

INNOVATION: Past and Future

By WILLIAMSON MURRAY

Mid-air refueling,
Rockwell Field,
California.

DarkStar UAV.



U.S. Air Force Historical Center

We have entered a period of uncertainty where threats are indeterminate even as changes in technology accelerate. Rapid innovation—apparent in the impact of stealth and precision weaponry in the Gulf War—appears likely to continue. Yet the Armed Forces are not apt to receive anything close to the resources enjoyed during the Cold War. With less money and greater ambiguity on the nature of opponents and wars in the future, we must innovate. Recent case studies of innovation in a similar period—the 1920s and 1930s—when

military institutions confronted great international uncertainty, relatively low support, and substantial technological change, offer views on how one might view innovation in the next century.¹

Many difficulties confront historians in drawing guidance from the past. It is impossible to replicate conditions of war in peacetime, while war itself is so permeated with fog and friction that it is difficult for military organizations to determine what has actually happened on the battlefield.² Since we prepare for and fight war in the real world rather than on computers, military innovation and adaptation reflect the complexity of that reality—one in which, as science increasingly reveals, chance and nonlinear factors dominate. For the analyst of innovation, complexities of the

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Higgins ramped
landing boat, 1941.

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process make it extraordinarily difficult to recover the past in a simple, digestible form. Relations among technological innovations, fundamentals of military operations, and changes in concepts, doctrine, and organization that drive innovation are essentially nonlinear. Changes in inputs such as weapon systems—large or small—may not yield proportionate changes in outputs or combat dynamics. And the impact of changes on doctrine or the education of an officer corps is almost incalculable.

Reading the past requires understanding how interactions actually work.

Since the 1950s, research from fields as diverse as meteorology, ecology, physics, and mathematics has uncovered numerous dynamic systems so simple as to represent virtual paragons of deterministic, clockwork mechanisms; yet they can give rise to long-term behavior so complex as to be literally unpredictable or chaotic. It now appears that stable systems with simple and predictable dynamics are in fact the exceptions in nature rather than the rule. And most crucially, the local randomness of nonlinear systems is

basic: gathering and processing more information with better algorithms and computers cannot, even in principle, make the unpredictability go away.

The implications of these developments sug-

gest that the world as a whole does not work in a mechanistic, deterministic fashion; that complex social interactions such as military innovation or actual combat do not reduce to simple linear processes; and that the study of human affairs—the interplay of thousands of independent variables—is more of an art than a science. The process of innovation in military institutions and cultures, involving myriad actors, complex technologies, and uncertainties of conflict and human relations, forms a part of this world and is no more subject to reductionist solutions than any other aspect of human affairs.

An Evolutionary Phenomenon

With the possible exception of the British air defense system developed by Hugh Dowding during the late 1930s, an innovation that flew in the face of airpower theories, bringing new ideas and concepts of fighting to fruition was a long process in the interwar years. This suggests that effective military innovation is evolutionary rather than revolutionary. To the British and French in summer 1940, the unfolding of German exploitation tactics, *Blitzkrieg* warfare, doubtless appeared as revolutionary. But to Germans involved in the process since the 1920s it seemed evolutionary.

While the degree of alteration on a year-to-year basis can be relatively small, gradual and cumulative change can be dramatic over time. The contrast between French and German tactical systems could not have been more striking in May 1940, but innovations that led to this breaking point took two decades. However gradual the changes, a chasm existed between how these two forces thought about, prepared for, and executed on the battlefield.

Evolutionary innovation depends on organizational focus over time rather than guidance by one individual for a short period. Military leadership can affect the process through long-term cultural changes rather than short-term decisions. Interwar development of armored warfare offers some perspectives. The most influential leaders were Lord George Francis Milne of Britain and General Hans von Seeckt of Germany. Milne was the more willing to see the army of the future in terms of armored forces. He not only supported armored maneuvers with scarce funds but told his senior officers in the 1920s:

It is up to us to find some means of bringing war back to what it was when the art of generalship was possible. The only means of doing this is to increase mobility on the battlefield. Now that is the point of the initiation of the armored brigade—to revive the possibility of generalship.³

Seeckt, though interested in motorized warfare, never got to that point. In 1928 he cautioned the *Reichswehr* officer corps that he did not foresee motorized soldiers entirely replacing horsemen.

But the significant issue is that Seeckt fostered a culture of innovation through the kind of officer corps he created in the early 1920s and the institutional values he inculcated. His officers developed doctrinal concepts based on past as well as current experience.⁴ In 1920 he established 57 committees to study the lessons of World War I.⁵ This effort produced the basic *Reichswehr* interwar doctrine manuals that had such influence on the *Wehrmacht*. This is an important point. There is an old axiom that generals prepare for the last war. In

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Launching
USS Lexington, 1925.

F4B-1 taking off
from USS Lexington.

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F6Cs and T3Ms aboard
USS Lexington off
San Diego, 1928.

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fact most military organizations show little interest in studying the lessons of even recent conflicts. Rather, they ignore the past or look to another paradigm. But the Germans were different.

Based on the *Reichswehr* study, Werner von Fritsch and Ludwig Beck—who became the army commander and the chief of the great general staff, respectively, when Adolf Hitler came to power—wrote *Die Truppenführung* in 1932, the chief army doctrine manual that the *Wehrmacht* used with such effect during World War II. The values Seeckt imparted to the *Reichswehr* placed a high value on analysis of changes in doctrine, tactics, and technology. In other words he created an ideal climate for innovation.

Milne, on the other hand, took over the British army well after World War I. That force had done little to examine its experience in the war, and Milne would not begin such an effort until his last year as the chief of the imperial general staff (IGS). Moreover, the regimental system

put little value on professional study of war.⁶ Consequently, Milne's influence was wholly personal and dissipated rapidly in the 1930s after his retirement and a series of unimaginative leaders took control. These officers, particularly Field Marshal Archibald Montgomery-Massingberd (Milne's successor), effectively sabotaged his initiatives.⁷ It thus appears that long-term decisions which affect the culture and values of the officer corps are crucial to innovation, while it is difficult for a single individual to institutionalize change.

Launching *USS Nautilus*,
Mare Island Navy Yard,
1930.



Curtiss OC-1 Falcon.



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Success in Innovation

Despite difficulties, some military institutions did innovate with success during the inter-war period. Others, however, failed dismally. The factors that led to success thus show what will be conducive to future innovations. Perhaps the most crucial factor is military culture. One might define military culture as the sum of intellectual, professional, and traditional values possessed by an officer corps. It is key to how officers assess the external environment and respond to threats. It is also crucial in how forces prepare for combat and innovate.

As suggested above, the German officer corps met many of these criteria. They in effect incorporated innovations in armored warfare through a comprehensive and realistic understanding of modern warfare. Steady and incremental improvement in tactics as well as doctrine resulted

in mechanized forces with capabilities well beyond those of other European armies. Essential to this success was the German ability to conceptualize the operational as well as tactical levels of war in doctrinal writings.

Thus *Die Truppenführung* provided the army with a coherent framework for thinking about future battlefields. It not only offered a means of integrating the traditional branches—artillery and infantry—but latitude to incorporate evolving concepts of armored war and close air support within a doctrine aimed at fighting mobile, decentralized battles. Since German officers took doctrine manuals seriously they could comprehend the larger picture of combined arms. Once exposed to the possibilities of armor in the Polish campaign, many skeptics were converted.

Moreover, there was honest reflection on future developments. For example, the German high command and general staff subjected army performance in Poland to a searching analysis in which operational success was not the major criterion. In Britain, on the other hand, Montgomery-Massingberd in the early 1930s suppressed the Kirk report on the performance of the British army in World War I because it was critical. That would have been inconceivable in Germany.

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P-39N, 1943.

This culture of critical examination transcended the learning processes about the last war. Throughout the late 1930s one sees the same pattern as the Germans conducted exercises and then combat operations. In all cases they continued to critically assess what had occurred in the field. Thus they learned from mistakes. Key to their approach was the treatment of errors in using new equipment or procedures. They saw mistakes as a learning experience, not a cause for reproof.

During this period German army culture provided for trust and honesty among command levels. Commanders were not afraid to admit that their units had problems. The *Anschluss* is a good illustration of this process, as the occupation of Austria in March 1938 indicated weaknesses throughout the participating units. After-action reports from battalion to army level became ever more critical of troop performance, training, and discipline in higher levels of command.

But cultural problems robbed Germans of the advantages gained in tactical and operational innovations. The most brilliant battlefield success could not make up for logistic and intelligence systems that failed to function in the modern world. Given the contempt on the part of their officer corps for these crucial areas—the *Luftwaffe* and navy were as bad as the army—the Germans were unable to engage in prolonged struggle. If tactical innovations gave the *Wehrmacht* an advantage early in World War II, they could not triumph over gross mistakes in strategy, logistics, and intelligence made largely as a result of military culture.

German officers were not alone in benefiting from a culture that encouraged innovation. Carrier aviation in the U.S. Navy offers lessons about successful military change in the interwar period.

Navy culture created a realistic relationship between annual exercises and education and wargaming at the Naval War College. Developments in carrier aviation largely rested on academic processes. The college designed summer fleet problems, the fleet executed them realistically, then a careful evaluation funneled the results back to Newport. Finally the college, well connected with the fleet, kept officers informed on developments in naval aviation and concepts for employing it. Moreover, the Navy sent its best officers to the Naval War College.

The realism and imagination of the war-games at Newport are particularly striking. As early as 1923, a game involved a blue fleet of five aircraft carriers against an opponent with four. While some games cast carriers in the mundane role of spotting for a battlefleet, the blue forces launched a strike of two hundred aircraft armed with bombs and torpedoes which crippled enemy carriers and a battleship. As Steven Rosen observed in his study of innovation:

Most important, concepts essential in the conduct of carrier war were worked out. The necessity of massing aircraft for strikes was highlighted. Rather than assigning aircraft to each battleship to act as its eyes, they were launched and kept in the air until large numbers could be assembled for an independent strike. The need for a coherent air-defense plan to coordinate the use of defensive aircraft was emphasized, and the commander of the red fleet was faulted for failing to come up with such a plan.⁸

The Navy approach to wargaming was similar to that of the German army. Neither used exercises or games to justify current revealed doctrine or exclude possibilities not popular among senior officers. In other words, exercises and games aimed at those questions that one might ask, not at solutions. In peacetime they were educational. In war they showed possibilities. The most important German game for crossing the Meuse, for example, held in March 1940, did not resolve whether *Panzer* spearheads should make the breakthrough by themselves or wait for the infantry.⁹

Perhaps the greatest interwar contribution which military culture made to innovation was in allowing officers to use their imaginations. Where that did not exist or military colleges inculcated an absolutist doctrine—as in the French army or at the U.S. Army Air Corps Tactical School—the result was flawed military innovation.

Failure to Innovate

Italians were the least successful innovators of the interwar period. While Anglo-American

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and German historians once blamed Italian failures on ethnic characteristics, recent scholarship has placed it where it belongs—on an officer corps that failed its nation and soldiers.¹⁰ A remark by General Ubaldo Soddu suggests the pervasive culture of the Italian military: “When you have a fine plate of pasta guaranteed for life, and a little music, you don’t need anything more.”¹¹ Any staff or war college that emphasizes golf and “getting in touch with the family” is not about to provide the intellectual climate for innovation.

Evidence throughout the interwar period suggests a wide-scale pattern of failing to innovate which reflects a larger problem of military effectiveness. As one commentator on the performance of military institutions from 1914 to 1945 noted:

Thus in the spheres of operations and tactics, where military competence would seem to be a nation’s rightful due, the twenty-one studies [on separate national military experiences] suggest for the most part

over the fleet air arm and the loss of most naval airmen to the RAF in 1918 made innovation almost impossible, at least compared to events in the United States and Japan.

Distinct barriers to innovation appeared throughout the 1930s. Perhaps the most obvious is a willful desire to discard history or twist it to justify current doctrine and beliefs. In 1924 the British air staff explicitly rejected the past in a memorandum to the chiefs of staff committee which argued that the force attacking an enemy nation:

... can either bomb military objectives in populated areas from the beginning of the war, with the objective of obtaining a decision by moral effect which such attitudes will produce, and by the serious dislocation of the normal life of the country, or, alternatively, they can be used in the first instance to attack enemy aerodromes with a view to gaining some measure of air superiority and, when this has been gained, can be changed over to the direct attack on the nation. The latter alternative is the method which the lessons of history seem to recommend, but the air staff are convinced that the former is the correct one.

This dismissal of history reflected the attitudes of most air forces in those years. Unfortunately for crews in World War II, the lessons did matter. The most glaring message of World War I was that the bomber only got through and back under fighter escort. Yet there was a pervasive belief in the RAF and the U.S. Army Air Corps that long-range fighters were not needed, possible, or relevant to strategic bombing. Air combat had repeatedly stressed during World War I that air superiority was essential to all air operations, particularly bombing. Without fighter support, attacking aircraft took prohibitive losses. But it took innumerable Schweinfurts and Nurembergs before air staffs of the next war awoke to that fact.

If military organizations sometimes ignore the past, they can also misuse it. The French, seeing the disasters that resulted from offensives in 1914, 1915, and 1917, wrote off any approach to offensive warfare other than their stylized, tightly controlled “methodical battle.” Their defeat in 1940 displayed the quality and inevitability of a Greek tragedy; but it is hard to see how they could have developed another attitude on offensive operations. Nevertheless, the French interpretation was basically flawed and historically inaccurate. During the late 1930s General Maurice Gamelin exacerbated a faulty doctrine by shutting off all debate within the French army.

More difficult to explain is the reaction of most navies to the unrestricted submarine warfare during World War I. In retrospect, Germany almost broke Britain’s sea lines of communications in 1917. Yet when the war was over, the



U.S. Army Military History Institute

France, 1918.

*less than general professional military competence and sometimes abysmal incompetence. One can doubt whether any other profession in these seven nations during the same periods would have achieved such poor ratings by similarly competent outside observers.*¹²

Misuses of History

Failing to innovate is more than simple incompetence. Some military institutions may have compelling reasons not to innovate or circumscribe possibilities. In the case of the development of British carrier aviation, the arguments



XAF radar antenna,
USS New York, 1938.



Testing radar on board
USS Leary, 1937.

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Kriegsmarine wrote the U-boat off as a major weapon and based its hopes entirely on rebuilding a high sea fleet of battleships (and virtually no carriers). Ironically, in 1936 Admiral Karl Doenitz and his chief engineer pushed the naval high command to support development of U-boats with a higher underwater speed—what would eventually become the Walter U-boat. But senior admirals displayed no interest in technology for a form of naval war they had dismissed.¹³ The Royal Navy also wrote off the submarine. On the basis of their victory in World War I and their development of sonar, the British gave up on antisubmarine warfare and threw themselves entirely into ensuring that Jutland would never happen again.

But the Japanese made the most amazing misuse of submarines despite their “long lance” torpedo, the finest undersea weapon of the war. In the face of the lessons of World War I and the Battle of the Atlantic in 1940–41, they failed to

attack U.S. sea lines of communications. At the same time they devoted few resources to protecting their own commerce. In the end they lost their merchant shipping to U.S. submarines while inflicting hardly any damage on enemy shipping.

Rigidity

One fact of life in many organizations that has had a ominous influence on the institutional capacity to innovate is rigidity. It appears in many areas, especially doctrine. There are reasonable explanations for French offensive doctrine remaining rigid throughout the interwar period. Harder to fathom is why it stayed so fixed in regard to defensive warfare.

The French also believed the Germans could not and would not ultimately perform radically differently from their own forces. They refused to recognize that an enemy had other options and might exercise them. It was mirror imaging of the worst sort. Immediately after the defeat of France in 1940, historian Marc Bloch (a French reserve officer who observed the collapse at highest levels), identified one major cause of this disaster: “our minds [were] too [in]elastic for us ever to admit the possibility that the enemy might move with the speed which he actually achieved.”¹⁴

This inflexibility was aggravated by an institutional bias against feedback that contradicted existing doctrine or preparations. Exercises aimed at inculcating “revealed truth” into units—not at adapting doctrine to real life. There was little learning since the high command had all the answers.



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Parachuting over
Brooks Field, Texas,
1926.

**the interwar period reveals
the need for officers to be
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to innovate**

The British army showed no greater interest in growing from exercises and had no effective system to disseminate lessons learned through its units. Even during the war there is little evidence that they incorporated battle experience in training.¹⁵ There was ample data from the Middle East, but Home Forces appeared to pay virtually no attention to it. Divisions working up for combat had to innovate and adapt almost on their own. Hence tactical innovation came on the battlefield—a most expensive teacher. An armor officer in North Africa described the results:

*Other officers told me of how they had seen the Hussars charging into the Jerry tanks, sitting on top of their turrets more or less with their whips out. "It looked like the run-up to the first fence at a point-to-point," the adjutant described it. The first action was very typical of those early encounters involving cavalry regiments. They had incredible enthusiasm and dash, and sheer exciting courage which was only curbed by the rapidly decreasing stock of dashing officers and tanks.*¹⁶

Such rigidity led organizations to shut off alternative paths. The belief that bombers would always get through led airmen to minimize the potential of the *Luftwaffe* to interfere with bomber operations. For the Royal Air Force and U.S. Army Air Forces, it meant minimizing technological support to aid the accuracy of attacks at night and in bad weather. The measure of air effectiveness thus became the number of sorties flown or targets attacked, tonnage of bombs dropped, and acres of cities destroyed. Air war had become an end in itself, and real measures of effectiveness simply failed to interest most air commanders.

Certainly the most rigid interwar military was the Soviet army. Stalin's purges ensured the loyalty of Soviet military institutions. Most innovation ceased and the officer corps chased after mindless conceptions of revolutionary war which severely damaged its capacity to fight and made it incapable of grasping how the *Wehrmacht* would fight. The outcome was the most catastrophic defeat in history in terms of human losses. The Soviets escaped its consequences only because of the appalling strategic and political misjudgments of their opponent.

Implications

There are some parameters for successful innovation. First, one must not think in terms of individuals—future Mitchells, Dowdings, Guderians—in furthering change. The interwar period reveals the need for officers to be educated and encouraged to innovate—a far larger problem than finding one innovative officer. Education and values are basic factors in innovation. Professional military education (PME) was vital to change in the interwar years and will be more so in the future if it provides the broad conceptual context that innovation requires.

In the larger picture, educational values among officers require an intellectual and physical commitment. Only a willingness to think through the business of war allows leaders to perceive the long-term potential of innovation. Moreover, officers must have connections with, and an understanding of, civilian technologies dominated by innovation. Military institutions must judge future war realistically. Here the muddy boot world of exercises and lifelike wargames lies at the heart of effective innovation. The development of German armor doctrine and close air support and of American and Japanese carrier aviation shows the relationships among education, doctrine, wargames, and exercises. When military organizations and high commands "knew" the answers and drove the solutions, the results were sometimes disastrous in stifling innovations.



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B-9 bomber.

What does the past imply for those who will innovate during periods of low budgets, major technological changes, and uncertain strategic conditions? First, specific, detailed plans to enhance innovation are probably a nonstarter. Courses on it at staff and war colleges will offer little, and creating innovation specialties may only attract those interested in a safe career rather than crusaders for change. Efforts to institutionalize innovation will inhibit rather than foster the process. Change demands officers in the mainstream of their professions, with a prospect of reaching the top ranks, who have peer respect and will take risks. The bureaucratization of innovation—particularly in the current framework of the U.S. military—guarantees its death.

How then to encourage it? The best route appears to be to foster change in service cultures. But one can only achieve cultural changes over the long haul, not a traditional American approach.

Areas where the Armed Forces might push the process are listed in conclusion.

- The services must think in terms of fighting real opponents, with real capabilities and real strategic and political objectives. Exercises and gaming must take place within concrete scenarios against realistic opponents

who can truly challenge blue forces. Such scenarios must examine the impact of innovative approaches on all three levels of war: strategic, operational, and tactical.

- The services must rethink their operational tempo and the number of annual exercises. The value of exercises, particularly when resources are short, lies not just in their conduct but their planning and lessons-learned analysis. The latter must involve more than reports no one reads, but rather rethinking doctrine, training, and education at every level. The value of exercises ultimately depends on the preparedness of participants to think through what went well and what did not.

- The services must ensure that lessons learned focus on more than validating doctrine and processes. During the interwar period the French sought seriously to examine World War I and learn from exercises. But they also created a system that narrowly constrained exercises and study and that ensured the sanctioned approach would again prove. They learned what made generals and staff officers happy, a clear case of self-fulfilling prophecy, at least until the Germans arrived on the banks of the Meuse.

- At every level the services must think in discrete measures of effectiveness. They need to consider exactly what they wish to do to an opponent. And as war changes, they will require new measures and methods. Above all, the services must foster a climate of military professionalism.

■ The services also need to rethink PME. Much interwar innovation depended on relations between the staff and war colleges and the world of operations. Unfortunately, the Armed Forces lost much of their belief in PME following World War II despite the testimony of Eisenhower and Spruance who credited their days at Leavenworth and Newport for their success. But any attempt to encourage cultural changes and foster intellectual curiosity demands better PME. It also requires that education remains central throughout an officer's career. One may not create another Seeckt or Dowding and manage his career through the ranks, but one can foster military culture where those so promoted have imagination and intellectual grounding to support innovation.

■ Finally, the services must encourage greater familiarity with nonlinear analyses. A heavy emphasis on engineering, which is prominent in the officer acquisition procedure of three services, reflects a mind set that is not conducive to innovation. While some suggest that the military needs more engineers to encourage nonlinear thinking, they are wrong. In fact what the services lack are biologists, mathematicians, and historians. Presently most senior officers think of innovation the way the *Luftwaffe* did during World War II, in quantitative and qualitative terms of techniques and platforms rather than conceptually.

JFQ

NOTES

¹ See Williamson Murray and Allan R. Millett, *Military Innovation in the Interwar Period* (New York: Cambridge University Press, 1996). This article was adapted with permission of the publisher from a chapter in the above book. The author would like to acknowledge the assistance of Barry Watts in preparing the article.

² Despite claims that technological change will stop friction, there is compelling evidence to the contrary. See Barry Watts, "Friction in the Future," in *Brassey's Mershon American Defense Annual, 1996–1997* (Washington: Brassey's, 1996).

³ B.H. Liddell Hart, *The Memoirs of Captain Liddell Hart*, vol. 1 (London: Cassell, 1965), p. 129.

⁴ Williamson Murray, "Armored Warfare: The British, French, and German Experiences," in *Military Innovation*.

⁵ James S. Corum, *The Roots of Blitzkrieg, Hans von Seeckt and German Military Reform* (Lawrence, Kans.: University Press of Kansas, 1992), p. 37.

⁶ Brian Bond, *British Military Policy between the Two World Wars* (New York: Oxford University Press, 1980).

⁷ Harold Winton, *To Change an Army: General Sir John Burnett-Stuart and British Armored Doctrine, 1927–1938* (Lawrence, Kans.: University Press of Kansas, 1988), pp. 130–31.

⁸ Steven Peter Rosen, *Winning the Next War: Innovation and the Modern Military* (Ithaca, N.Y.: Cornell University Press, 1991), p. 69.

⁹ Heinz Guderian, *Panzer Leader* (Washington: Zenger, 1979), p. 71.

¹⁰ MacGregor Knox, *Mussolini Unleashed, 1939–1941, Politics and Strategy in Fascist Italy's Last War* (New York: Cambridge University Press, 1982), p. 16.

¹¹ *Ibid.*, p. 57.

¹² John H. Cushman, "Challenge and Response at the Operational and Tactical Levels," in *Military Effectiveness*, volume 3, *World War II*, edited by Allan R. Millett and Williamson Murray (London, Allen and Unwin, 1988), p. 322.

¹³ John Terraine, *The U-boat Wars, 1916–1945* (New York: Putnam, 1989), p. 617.

¹⁴ Marc Bloch, *Strange Defeat* (New York: Norton, 1968), p. 45.

¹⁵ Williamson Murray, "British Military Effectiveness," in *Military Effectiveness*, vol. 3, pp. 90–135.

¹⁶ Robert Crisp, *Brazen Chariots* (New York: Ballantine, 1960), p. 32.



1st Combat Camera Squadron (James E. Lotz)



55th Signal Company (Cory Montgomery)



USS Seawolf (John E. Gay)



U.S. Marine Corps

what they've said in JFQ

***it is hard to think of a nonmilitary role without precedent for
such roles are as American as apple pie***
—Samuel P. Huntington

***the mission and the Rwandans fell victim to inflated
expectations that the United Nations could not fulfill***
—R.A. Dallaire and B. Poulin

***Roosevelt knew that generals could make disastrous
military mistakes, not merely political ones***
—Eliot A. Cohen

***evolutionary innovation depends on organizational focus over
time rather than guidance by one individual***
—Williamson Murray

***to achieve more efficient use of defense resources, Congress
looked to the Chairman***
—James R. Locher III

***advanced courses on proliferation and counter-
proliferation reach only a small fraction of students***
—Robert G. Joseph